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SOIL MOISTURE, UNDERSTORY COMPETITION, AND TREE GROWTH
IN FOUR SHELTERBELTS IN SOUTHEASTERN NORTH DAKOTA

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A PROGRESS REPORT

SUBMITTED TO

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

U. S. Department of Agriculture, Forest Service

Fort Collins, Colorado

June 1970

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During and shortly after the great drought of the 1930's, the United States Forest Service initiated and sponsored a program of shelterbelt (windbreak) plantings in the Great Plains region. These plantings, consisting of from one to many parallel rows of trees, usually oriented along cardinal compass directions, were cultivated through the early years to insure establishment of the planted trees. As time went on, the cultivation was abandoned. Rainfall was adequate for tree growth, at least in eastern North Dakota, the saplings had survived the early critical years, and farm machinery became too large to work in the belts. Few farmers today have tractors that could successfully navigate between the rows of trees.

As a result of this abandonment, a dense understory of forbs and grasses, shrubs and saplings is now present in most belts, and in many belts, the older trees are beginning to weaken and die. The cause is unknown, but it may be attributed, perhaps, to an actively competitive situation involving the understory and a variety of environmental factors or complexes, some of which may be in short supply. If this is true, then it should be possible to attack this problem experimentally, eliminate the understory competition in a test area, and then study both the behavior of selected environmental characters and tree growth.

In the early summer of 1968, four shelterbelts in southeastern North Dakota were selected in order to study the effects of understory competition on tree growth. Although it was suspected that mineral nutrients might play a significant role, in the early stages the study has been limited to aspects of soil moisture. By using an experimental treatment, the removal of understory vegetation, it should be possible to determine the moisture utilization by the understory vegetation, i. e. that portion of the soil moisture unavailable for tree growth and function.

The four selected belts were chosen from a larger sample used by Naylor (1969), in order to eliminate duplication of effort. Naylor's data were available. In addition, proximity to Fargo was important, because each belt had to be visited frequently. Finally, to attempt to analyze as many variables as possible, two belts were selected on heavy (clay) soils, one with a predominantly grassy understory, the other with a predominantly woody layer, and two on light (sandy) soil, again with the above understory considerations (Table I.). In addition to these specific requirements, all belts had to be at least 25 years old, contain a minimum of five rows and a minimum of five tree species, and they had to be oriented the same way. The four belts finally selected met all criteria, and all lie along east-west section or half-section lines.

After obtaining permission from the individual belt owners to institute the treatment, a homogeneous 200 foot segment was selected in each belt and half (a 100 foot segment) was clean-cultivated. This cultivation proved to be difficult. Machetes, axes, and saws were necessary at both Kindred and Arthur (the woody belts) before a small tractor could even get between the rows. Then a tractor and three-row cultivator were used to clear most of the understory. About a week later a hand Roto-Tiller was used on the treatment area in each belt, followed periodically by hoeing and hand-pulling of weeds. Roto-tilling was necessary again in the spring of 1969, and intermittent hoeing has helped to keep the treatment area free of plant growth. Nevertheless, the attempts to eliminate all understory competition have had uneven results, Grandin and Arthur being virtually clean, and Buffalo and Kindred a constant battle. It is immediately apparent, however, that 95 - 99 percent of all understory has been eliminated in the treatment plot in each belt.

Ten trees of each of five species in each belt were then selected and marked, five in the cultivated portion and five in the native, i. e. uncultivated portion. At the end of the growing season in both 1968 and 1969, height and diameter (at breast height) were measured on each marked tree.

Six rain gauges were set in each belt, three in each segment, filled with .1 inch of mineral oil to retard evaporation, and read, emptied, and reset once each week.

Each week six holes were bored in the soil in each belt, again three in each segment at random. Holes were bored to a depth of six feet and a sample taken every six inches. A Veihmeyer tube and hammer were originally used, but it was almost impossible to remove samples of heavy, wet clay from the tube. Throughout 1969, a 1.5 inch diameter bucket auger was used, this proving to be much faster and far more efficient than the tube.

For bulk density samples, where a known volume of soil must be obtained, a tractor-mounted hydraulic probe was used, and again six holes were bored in each belt. Due to a great amount of compression in the tube in the clay belts, it was impossible to get adequate samples to the full 72 inch depth, hence some data are missing from this report.

Moisture retaining capacity of the soils was determined by the Hilgard cup method, and is defined as the amount of water, expressed as a percent of dry weight of the soil, that can be held against the force of gravity. Soil pH was determined by use of a Beckman Zeromatic III pH meter, and the permanent wilting point determinations were done by the Department of Soils, North Dakota State University, using the pressure plate method at 15 atmospheres.

All soils data were obtained from three replicate samples at each depth (six inch increments) in each segment of each belt. The values expressed in the tables, however, are often averaged for greater readability and condensation. Values expressed in 12 inch increments are averages of at least six separate measurements, three at each of the two six-inch depth increments, and if the data are not expressed separately for the cultivated and native portions of the belt, then the values represent averages of 12 measurements. While rigid statistical tests have not yet been applied to these data, it is reasonably certain that significant differences do not exist between treatment segments or between adjacent depth increments in those instances where the data have been lumped and averaged.

RESULTS AND DISCUSSION

Bulk density (Table II) and soil pH (Table III) do not appear to vary significantly between or among belts. There is a slightly higher bulk density value at depth in the Buffalo belt, but this belt shows a stony or gravelly layer starting at about three feet that might account for the higher bulk densities. The belt at Arthur, in spite of being classed as a sandy belt (based on surface textural analysis), lies in the border region between the heavy clays of glacial Lake Agassiz and the sands of the beach ridges, as mapped by the North Dakota Soil Survey. In addition, the percentage of silt and clay in the Arthur belt appears to increase with depth, although textural analysis has not been completed. These factors, though, would seem to account for the amazing similarity between the bulk density values for Arthur (sand) and those for Grandin and Kindred (clay).

The pH in all belts ranges from neutral to slightly alkaline, each

belt showing a slight increase with depth. It is doubtful whether pH seriously affects either tree or understory growth in the shelterbelts of eastern North Dakota. Farther west, where soils tend to be more highly alkaline, the alkalinity may be a significant factor, but the values in the four belts under study are well within the known tolerance limits for the tree species involved, and hence can probably be ruled out as a major influence.

Moisture retaining capacity (Table IV) shows the expected higher values in the clay belts, and the decrease with depth reflecting the incorporation of organic matter in the upper horizons. The higher values in the two clay belts should provide more water for plant growth, other factors being equal, which, of course, they are not. Hence the conclusion that water retaining capacity of the soil profiles involved is also a non-significant element in the shelterbelt environment.

The permanent wilting point (Table V) shows consistent values throughout each profile, with slightly higher percentages in the upper horizon. Of significance, however, is the fact that the permanent wilting point in the clay belts ranges from two to three times that of the two sand belts. Tight bonding of water on the clay particles probably accounts for most of this, and indicates the typical situation where soils will no longer supply water for plant growth even though the actual moisture content may be relatively high. This makes it imperative, then, that moisture content percentages be carefully analyzed in order to express real situations that have an impact on plant growth.

Tables VI and VII give the maximum, minimum, and seasonal average soil moisture percentages for the four belts, for both cultivated and native segments. All three statistics tend to be generally higher in the clay belts, although there is some variation. Surface horizons in the sands

tend to dry out to a greater degree as the season progresses. There is also a noticeable trend toward range reduction (maximum minus minimum) with depth, although a depth of six feet is still apparently above that point in the soil where moisture content would remain almost stable throughout the year, as moisture content still fluctuates down to that depth in the four shelterbelts studied. This trend toward a smaller range is extremely consistent no matter how the data are analyzed, and similar values are obtained between the two treatments of each belt, the clay belts versus the sand belts, the cultivated versus the native segments, and all other possible combinations. In all cases also, the magnitudes of these differences between maximum and minimum moisture percentages are similar.

The moisture content is important mainly as an index of soil water behavior over a period of time. In order to analyze its importance for plant growth, the interaction of bulk density, permanent wilting point, and moisture content may result in the calculation of a more meaningful statistic, the available water. This has been summarized over the growing season for each segment of each belt (Table VIII). It is readily apparent that in spite of generally higher moisture percentages in the clay belts, and notwithstanding their higher moisture retaining capacity, the sand belts supply vastly more water for plant growth, ranging up to twice as much per 12 inch increment as in the clay belts.

It is also evident that there is a marked treatment difference, one that appears to be quite interesting. Table IX is a crude analysis of the total available water in each segment of each profile based simply

on the difference between the values of the native versus cultivated segments in each belt. These differences were signed, totalled, and then averaged. They are expressed arbitrarily as the available water advantage of the native over the ~~cultivated~~ segment. It is shown that the Grandin value is strongly positive, Kindred slightly positive, Arthur slightly negative, and Buffalo strongly negative. The only plausible conclusion from these data is that cultivation in the clay belts decreases the available water, while cultivation in the sand belts increases it. It is suspected that the clay soils, with their high capillarity and small particle size may be subjected to an immense evaporation stress in a denuded (i. e. cultivated) condition. If this surface evaporation is greater than normal evapotranspiration and physiological assimilation by the understory vegetation, then there would be a net loss of available water in the cultivated segments of the clay belts. Conversely, if subsurface capillarity and subsequent evaporation from the sands is less than the amount of water normally used by the understory in these belts, then a net gain in available water would result from cultivation.

One other item merits mention here. The Grandin belt (strongly positive) and the Buffalo belt (strongly negative) are the two belts with predominantly grassy understory vegetation. In order for this situation to fit the hypothesis above, the grasses should be light and inefficient users of water in the clays and heavy and efficient users in the sandy soils. Conversely, the grass understory, either by its density or its composition, should be an efficient block to surface evaporation in the clay belts, and an inefficient block on the sands. The implications of this are unclear at this time, but additional data should help to clarify, if not answer, some of these questions.

Growing season precipitation is summarized in Table X. There are no striking differences among treatments or among belts. The slightly lower totals for Arthur and Buffalo reflect, I think, the slightly lower average annual precipitation encountered moving westward out of the Red River valley in North Dakota. These differences in totals are probably not significant, and in any event, their influence does not appear to show up in the available water data, where in spite of lower rainfall, all increments in each segment of each sand belt consistently possessed more water than the counterparts at Grandin and Kindred.

Tree growth within and among the belts is difficult to assess based on only one full growing season. All marked trees were measured in October 1968 and again in October 1969. A great deal of variation is present in both height and diameter measurements, with no consistency by species, soils, or treatments evident. In order to attempt an analysis of tree growth, all actual measurements of the 1969 growth increment were converted to percentages. In part, this accounts for possible differences in individual vigor at the start of the project, and would appear to obviate the genetically controlled differences in tree sizes and growth rates. Large, fast-growing species such as cottonwood are expected to register greater actual growths than smaller, slower-growing species such as Siberian elm or green ash.

Height and diameter growth for the five species of trees used (cottonwood, box elder, American elm, Siberian elm, and green ash) ranged from zero to about 12 percent. These growth percentages were then ranked and assigned class numbers from one through nine (Table XI). The class numbers were then averaged for all trees of a species in a belt segment resulting in a single index value for height and one for diameter growth.

Table XII summarizes the index values for all species in all belts. Again, there is a lack of consistency in the tree performance based on the single year of data. As an example, Siberian elm in the Grandin belt (clay) had an index value of one (1) for diameter growth in the cultivated segment, and a value of eight (8) in the native section. At the Kindred belt, also on clay, the values are exactly reversed.

When the index values are totalled, it appears that there is better diameter growth on both clay and sand in the cultivated segments, and better height growth on clay in the cultivated segments. No difference in height growth is indicated in the sand belts. While the data admittedly are inconclusive, there seems to be little, if any, correlation between tree growth and the moisture factor in the shelterbelts studied. Still, a growth rate difference does show up, and the indications are that the cultivation treatment to eliminate competition from the understory vegetation is beneficial to tree growth. Inasmuch as moisture does not seem to be a factor, the nutrient regime becomes a prime suspect that may account for the observed differences.

It is recommended, in view of the above tentative conclusions, that the study be continued for at least three more years. This would provide enough data on both the soil moisture situation and tree growth to adequately utilize statistical analysis and eliminate equivocation. In addition, at least pilot studies on the nutrient situation would seem to be indicated, and it is believed that this could be accomplished rather easily by soil analyses at the beginning and the end of the growing season. It is also strongly recommended, in the event that the project is continued, that a graduate research assistant be funded by the project. Some of the work the past two years has been made much more difficult than necessary due to the lack of a full-time man assigned to the shelterbelt studies.

Table I. Location and general characters of four shelterbelts in southeastern North Dakota.

Belt Name	Grandin	Kindred	Arthur	Buffalo
Naylor Number	159	140	108	123
County	Traill	Cass	Cass	Cass
Location	Sec. 20 T144N R49W	Sec. 15 T138N R51W	Sec. 2 T141N R52W	Sec. 18 T141N R 54W
Length (miles)	.5	.5	.5	.25
Percent Sand	14	10	72	78
Percent Silt	53	57	16	16
Percent Clay	33	33	12	6
Number of Rows	9	9	11	5
Number of Tree Species	7	7	8	5
Approximate Age in 1970 (years)	32	32	36	31
Understory Type	Grassy	Woody	Woody	Grassy

Table II. Soil bulk density (grams per cc), by 12 inch increments, in the four belts.

Belt	Grandin	Kindred	Arthur	Buffalo
Depth (in)				
0 - 12	1.06	1.06	1.10	1.18
12 - 24	1.32	1.29	1.34	1.27
24 - 36	1.39	1.41	1.40	1.56
36 - 48	1.45	1.47	1.39	1.52
48 - 60	1.37	1.37	1.40	1.61

Table III. pH, by 12 inch increments, in the four belts.

Belt	Grandin	Kindred	Arthur	Buffalo
Depth (in)				
0 - 12	7.0	7.0	7.0	7.6
12 - 24	7.2	7.2	7.4	7.8
24 - 36	7.8	7.5	8.1	7.9
36 - 48	7.9	7.9	8.2	7.9
48 - 60	8.0	7.8	8.1	7.9
60 - 72	8.0	7.7	8.1	7.9

Table IV. Moisture retaining capacity (%), by 12 inch increments, in the four belts.

Belt	Grandin	Kindred	Arthur	Buffalo
Depth (in)				
0 - 12	101	97	70	66
12 - 24	92	89	67	66
24 - 36	90	87	67	63
36 - 48	88	89	72	64
48 - 60	87	89	54	64
60 - 72	87	97	60	65

Table V. Permanent wilting Point (% dry weight), by 12 inch increments, in the four belts.

Belt	Grandin	Kindred	Arthur	Buffalo
Depth (in)				
0 - 12	28	23	12	11
12 - 24	24	21	9	10
24 - 36	22	22	9	9
36 - 48	22	23	10	10
48 - 60	22	24	7	10
60 - 72	25	--	10	10

Table VI. Maximum, minimum, and seasonal average moisture content percentages, by six inch increments, for the two clay belts, Grandin and Kindred.

Belt	Grandin						Kindred					
Treatment	Cultivated			Native			Cultivated			Native		
Depth (in)	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Maxx	Min	Ave
0 - 6	49.5	21.4	34.8	53.9	25.2	35.3	41.4	20.7	30.3	40.7	18.6	29.8
6 - 12	41.8	25.1	31.3	46.1	20.6	31.2	38.5	20.3	28.4	37.8	20.2	28.0
12 - 18	37.2	22.0	30.1	42.7	22.0	29.2	37.5	19.2	27.6	36.7	18.4	27.5
18 - 24	35.9	20.5	28.5	39.8	21.8	28.4	33.5	18.9	26.7	34.1	19.0	27.1
24 - 30	34.2	17.0	26.5	35.4	19.2	28.0	32.5	21.3	27.1	41.3	18.0	27.3
30 - 36	34.1	17.5	26.0	35.8	20.2	28.1	33.3	21.2	27.4	31.77	20.2	27.9
36 - 42	33.2	18.6	25.7	36.2	19.8	28.7	32.5	22.4	28.0	35.2	21.4	28.3
42 - 48	33.3	15.9	26.2	37.7	19.4	29.6	32.5	20.9	28.1	32.0	23.1	28.1
48 - 54	30.1	19.6	25.4	37.2	20.6	30.5	34.0	23.9	26.9	37.5	23.7	27.1
54 - 60	32.4	18.9	26.4	40.0	26.4	33.8	44.0	23.9	27.5	31.4	23.9	26.3
60 - 66	32.4	22.6	28.3	39.4	28.2	34.9	32.0	24.4	27.5	27.5	25.4	26.6
66 - 72	37.6	19.0	31.0	41.4	34.1	37.2	29.3	26.5	27.9	31.0	26.1	28.2

Table VII. Maximum, minimum, and seasonal average moisture content percentages, by six inch increments, for the two sand belts, Arthur and Buffalo.

Belt	Arthur						Buffalo					
Treatment	Cultivated			Native			Cultivated			Native		
Depth (in)	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
0 - 6	33.3	13.3	21.2	34.7	13.6	23.7	29.7	9.9	20.0	33.3	7.6	16.4
6 - 12	27.1	11.9	20.0	26.8	11.3	19.8	28.8	10.9	19.5	31.0	8.9	17.8
12 - 18	27.9	10.6	18.8	24.5	10.1	18.5	26.7	10.0	16.9	26.6	9.7	19.0
18 - 24	26.9	9.3	18.5	23.6	10.7	18.6	33.6	9.7	15.5	27.4	9.7	17.6
24 - 30	27.5	12.9	20.6	27.0	13.1	20.2	33.0	8.3	16.0	29.0	9.4	16.5
30 - 36	28.7	15.8	23.6	28.8	17.0	21.8	32.6	11.9	16.2	28.4	10.3	17.3
36 - 42	33.2	13.5	26.3	36.1	17.3	25.1	35.0	9.6	17.4	34.3	11.9	17.0
42 - 48	37.7	24.9	30.1	34.3	19.4	27.4	40.3	13.0	18.8	33.6	11.7	17.7
48 - 54	37.7	28.2	32.4	33.7	14.4	27.3	21.2	11.3	16.9	21.2	12.8	16.5
54 - 60	42.1	28.1	33.6	32.5	15.9	27.3	20.6	12.1	17.0	20.7	13.6	16.9
60 - 66	35.5	27.3	32.5	35.0	24.3	29.3	19.0	15.4	17.4	20.1	14.7	18.1
66 - 72	34.9	28.0	32.8	33.3	22.2	29.2	19.7	15.4	17.7	19.5	14.6	17.8

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Table VIII. Seasonal total available water (inches), by 12 inch increments, in the four belts.

Belt	Grandin		Kindred		Arthur		Buffalo	
Depth (in)	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.
0 - 12	12.48	17.10	11.99	13.39	17.61	21.55	16.26	15.48
12 - 24	10.29	15.70	14.26	15.35	22.94	26.78	17.47	15.11
24 - 36	11.00	17.99	11.98	16.96	34.56	32.56	22.39	15.86
36 - 48	14.23	22.61	13.61	13.68	47.06	44.84	26.52	17.37
48 - 60	10.21	16.69	6.44	4.09	57.97	42.54	---	---

Table IX. Analysis of the average native segment over cultivated segment advantage in total profile available water in the four belts.

Depth (in)	Grandin	Kindred	Arthur	Buffalo
0 - 12	+ 4.62	+ 1.40	+ 3.94	- 0.78
12 - 24	+ 5.41	+ 1.09	+ 3.84	- 2.36
24 - 36	+ 6.99	+ 4.98	- 2.00	- 6.53
36 - 48	+ 7.38	+ 0.07	- 2.22	- 9.15
48 - 60	+ 6.48	- 2.35	-15.38	-----
Totals	+30.88	+ 4.19	-11.82	-18.82
Average per increment	+6.17	+ 0.84	- 2.36	- 4.70

Table X. Monthly total precipitation (inches) in the four belts, by treatment. Each value is an average of three gauges set in each segment of each belt.

Belt	Grandin		Kindred		Arthur		Buffalo	
Month	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.
June	2.25	1.96	2.50	2.36	.16	.15	2.09	2.05
July	5.83	5.40	7.79	7.78	6.88	6.58	2.20	3.33
August	1.24	1.12	.01	.01	.10	.10	.38	.48
September	2.43	2.48	1.45	1.72	2.34	2.26	3.53	3.78
Totals	11.75	10.96	11.75	11.87	9.48	9.09	9.20	9.64

Table XI. Tree height and diameter increment index scale.

Percentage Growth	Index
0.0 - 0.5	1
0.6 - 0.9	2
1.0 - 1.9	3
2.0 - 2.9	4
3.0 - 3.9	5
4.0 - 4.9	6
5.0 - 7.5	7
7.6 - 9.9	8
10.0 +	9

Table XII. Height and diameter index values for all species in each segment of each belt.

Species	Box Elder		Cottonwood		American Elm		Siberian Elm		Green Ash		Total		Combined Total		
	Belt	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.	Cult.	Nat.
Diameter	Grandin	2	1	1	1	1	1	1	8	1	1	6	12	26	19
	Kindred	1	3	3	1	3	1	8	1	5	1	20	7		
	Arthur	5	1	1	2	7	1	1	1	1	1	15	6	25	9
	Buffalo	-	-	3	1	2	1	-	-	5	1	10	3		
Height	Grandin	4	1	1	3	1	1	4	1	4	1	14	7	32	15
	Kindred	3	1	3	1	4	1	7	1	1	4	18	8		
	Arthur	1	4	3	1	1	6	1	2	2	1	8	14	19	19
	Buffalo	-	-	1	3	6	1	-	-	4	1	11	5		